Hrvatski meteorološki časopis – Croatian Meteorological Journal, 44/45, 2011., 31–46.

Prethodno priopćenje

THE METEOROLOGICAL ASPECTS OF THE DART FIELD EXPERIMENT AND PRELIMINARY RESULTS

Meteorološki pogled na DART eksperiment i preliminarni rezultati

MARTINA TUDOR

Croatian Meteorological and Hydrological Service,
Grič 3, HR-10000 Zagreb, Croatia
martina.tudor@cirus.dhz.hr

Prihvaćeno: 30.3.2009. u konačnom obliku: 30.4.2009.

Abstract: DART (Dynamics of the Adriatic in Real-Time) is a project devoted to real time observational and modelling study of the Adriatic Sea involving a considerable number of organisations from Europe and US. Several ocean and wave models were run using different meteorological model outputs for input atmospheric conditions. Two field campaigns (research cruises) were organised, during March and August 2006. This paper presents the role of meteorology and operational meteorological models in an oceanographic research cruise. Real-time measurement and model capabilities are described in detail with brief analysis of two severe weather events.

Sažetak: DART (Dynamics of the Adriatic in Real-Time = Dinamika Jadrana u Realnom Vremenu) je projekt posvećen mjerenjima i modeliranju Jadranskog mora u realnom vremenu koji uključuje veliki broj organizacija iz Evrope i Sjedinjenih Država. Nekoliko numeričkih oceanografskih modela kao i modela visine valova je davalo prognozu stanja Jadranskog mora koristeći ulaz iz različitih meteoroloških modela. Organizirana su dva istraživačka krstarenja, tijekom ožujka i kolovoza 2006. U ovom radu će biti prikazana uloga meteorologa i operativnih meteoroloških modela na krstarenju posvećenom oceanografskim mjerenjima. Mogućnosti dobivanja mjerenih i modeliranih podataka u realnom vremenu su detaljno prikazane, s kratkim osvrtom na dvije situacije s opasnim vremenskim neprilikama.

1. INTRODUCTION

DART (Dynamics of the Adriatic in Real Time) is a research project that addresses observational and modelling capabilities on small-scale instabilities in the Adriatic Sea during winter and summer conditions and gather a set of measured as well as model data of ocean and atmospheric properties. The Adriatic sea was chosen to conduct this research since it is covered by several operational models running in the area and supports a wide range of processes due to varying environmental factors. The main phenomena of interest were small-scale instabilities of the ocean flow of central Adriatic, the western Adriatic current and sea water transport over the Palagruža Sill. 35 institutions from 8 countries participate in the project contributing with measured data and providing model runs. Among them was the Meteorological and Hydrological Service of Croatia.

The main purpose was to evaluate observational and modelling capabilities accessible on the field. One of the goals of this project is to improve the understanding of the air-sea interaction evaluating models using measured data collected during the field trials. The air-sea interaction project of the DART experiment searched for improvement in the forecast skill of the surface drift as a consequence of improvements in the air-sea interaction and coupling formulations both in meteorological and oceanographic models. Aladin-Croatia forecast was used for driving ocean and wave model operational forecasts as well as to provide weather forecast that was used when planning the schedule of instrument recoveries and deployments and other weather-sensitive operations.

The DART project utilized NRV (Naval Research Vessel) Alliance for special measurements done at sea during two special observing periods: 27th February to 29th March and 13th to 31st August 2006. The ship hosted a number of scientists who performed measurements and analysed the data on board. During the field experiment, the vessel has served as a moving platform for many types of oceanographic measurements, mooring and retrieval of instruments from the sea bottom, continuous probing of the sea column as well as taking samples from the ocean floor. The same platform was used for only few meteorological measurements using the automatic meteorological stations available on board and to install and retrieve a meteorological buoy.

The aim of this paper is to describe what measurements were done during the trials, the meteorological aspects of the two field experiments and the preliminary results of the analysis of the observed phenomena as well as performance of meteorological models with the emphasis on Aladin-Croatia.

Following the introduction, the second chapter describes the available modelled and measured data. The field experiments and the observed weather characteristics are described in the third chapter. The performance of meteorological models used for the weather forecast on board are described in the fourth chapter where forecast data are compared to measurements. Finally, the discussion and conclusions defines the points where Aladin model may be improved and proposes several subjects for further research.

2. AREA OF INTEREST AND AVAILABLE DATA

The area of interest (Figure 1) was the central Adriatic, especially the Gargano-Split and Bari-Dubrovnik trans-section and the Gulf of Manfredonia. Aladin model data were provided from the Croatian meteorological service and used to run NCOM (Navy Coastal Ocean Model) oceanographic model and SWAN (Simulating Waves Nearshore) wave model at NRL (Naval Research Laboratory).

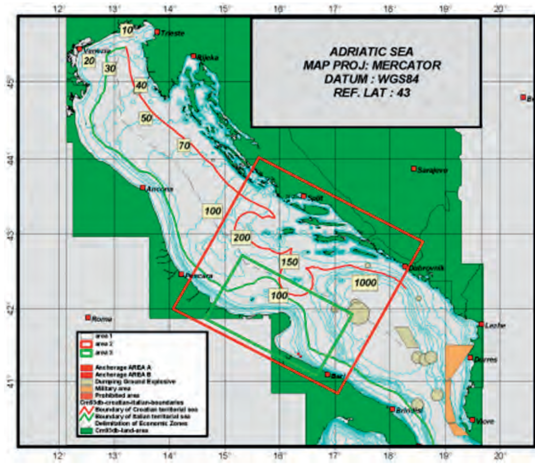

Figure 1. Area of interest of the DART project.

Slika 1. Područje istraživanja DART projekta.

2.1 Meteorological models

The meteorological model outputs on board the ship were used primarily for weather forecast to plan the operations at sea. They were also used to drive the ocean and atmospheric models, for the meteorological, wave and ocean model inter-comparison as well as comparison to measured data. The most useful meteorological fields were 10m wind, 2m temperature and relative humidity, mean sea level pressure, precipitation, radiation and heat fluxes.

During the field experiment, the existing modelling and observational systems were evaluated. The operational meteorological, ocean and wave models of different horizontal resolution were compared with data from local observations. Individual model to data comparison was carried in near real-time. The final set of different model and measured data was combined using the super-ensemble and hyper-ensemble techniques (Rixen et al. 2008).

2.1.1 ALADIN

The ALADIN model (Ivatek-Šahdan and Tudor, 2004) forecasts were provided by Croatian meteorological and hydrological service twice a day, starting from 00 and 12 UTC analyses. The operational forecast range in March 2006, during the first cruise, was 54 hours. It was prolonged in April 2006 and during the summer cruise it was 72 hours. The data were provided with a 3 hourly interval. Operational forecast is run on a Lambert projection domain of 240x216 points covering the whole Adriatic

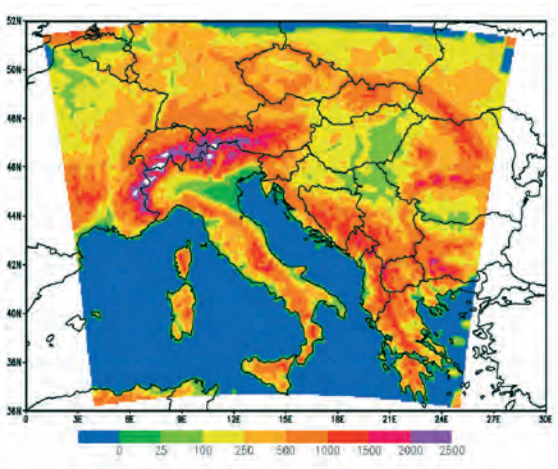

Figure 2. Terrain representation in the operational domain for ALADIN Croatia, 240x216 points, 8km horizontal resolution.

Slika 2. Visina tla u operativnoj domeni ALADIN Hrvatska, 240x216 točaka, 8km horizontalna rezolucija.

and surrounding areas with 8 km horizontal resolution on 37 levels in the vertical. The model domain and orography representation is shown in Figure 2. The lowermost level is about 17 meters above surface when the surface is on the sea level. Additionally, high resolution wind forecast with 2 km horizontal resolution was provided on four small domains covering the eastern Adriatic coast, as well as one more for the Gargano area.

Another set of ALADIN forecast data was the operational forecast of ALADIN-France provided by SHOM (Service Hydrographique et Océanographique de la Marine) covering only part of the Adriatic with 11 km horizontal resolution.

2.1.2 LAMI

LAMI (Limited Area Model Italy) is the local implementation of the LM (Lokal Model, Steppeler et al, 2002). It is non-hydrostatic numerical weather prediction model. LAMI operational forecasts were provided by ARPA-SIM on a daily basis. The forecast range was 72 hours, provided with 3 hourly interval. The forecasts started from 00 UTC analysis. The data were provided on a Lambert projection domain of 234x272 points covering the area around Italy, including the whole Adriatic area. The model is run with 7 km horizontal resolution. The model provides 10m wind, 2m temperature and relative humidity, total cloud cover, mean sea level pressure, precipitation and shortwave radiation.

2.2 Measured data

Measured data were analysed and preliminary quality controlled during the cruise. All the measured as well as modelled data were made available to all the team members on board Alliance through the server in the SACLANT NATO research center. During the research cruises, valuable in-situ measurements were collected of several processes in the Adriatic Sea, as the sea water exchange over the Palagruža sill between the central and southern Adriatic, the anomalies in the western Adriatic current or convective processes in the Adriatic Sea during winter.

The cruise schedule was adapted to the current situation in the field. First the general situation was observed and then some of the details in the measurement plan and a day to day schedule was adapted to the weather situation in the field as well as the occurrence of interesting transient phenomena in the sea currents that were detectable in the remote sensing data.

As most of the field experiments, DART also had as a goal a comprehensive data set describing oceanographic and meteorological phenomena in the given area and time, particularly central Adriatic during March and August 2006. The meteorological measurements relied mostly on the conventional measurements on SYNOP stations in Croatia, Italy and Montenegro and measurements on the automatic stations in Croatia. Additional in-situ measurements were provided by 3 automatic stations on NRV Alliance and 1 meteorological buoy moored in the Manfredonia bay. Satellite measurements of the sea surface temperature were also available. SODAR measurements were established on Split airport, but unfortunately measurements stopped before the first bura episode of the first field experiment on 6th March 2006.

2.2.1 Meteorological measurements

The measured data from the SYNOP and automatic meteorological stations were transferred to NRV Alliance in real time. Data from Croatian SYNOP stations were provided every hour, the data from Italy and Montenegro were

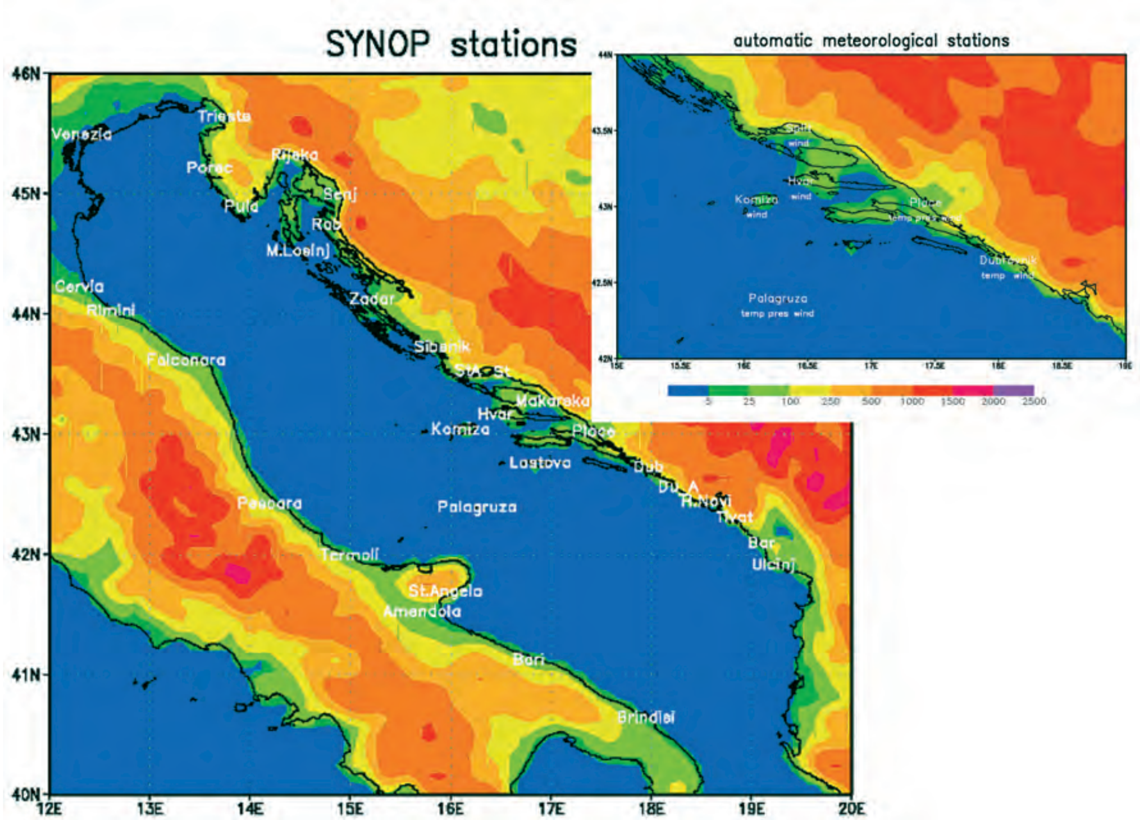

Figure 3. SYNOP stations and Croatian automatic stations relevant for the representations of meteorological conditions in the DART area of interest.

Slika 3. Sinoptičke i automatske postaje bitne za opis meteoroloških prilika na području istraživanja DART projekta.

provided with 3 hour interval as available in the GTS international exchange. The data from automatic stations were transferred every hour with a 10 minute interval. The positions of the SYNOP and automatic stations operational at the time and relevant for the area of interest are shown in Figure 3. Measured meteorological data was used for the verification and validation of model forecasts on board as well as valuable additional information describing the state of the atmosphere to be used as input for the wave and ocean models.

NRV Alliance is equipped with several measuring devices per each meteorological quantity (Figure 4). There are several types of barometers on the bridge as well as two sets of meteorological shelters for thermometers for measuring air and wet bulb temperature. There were 3 additional automatic meteorological stations installed on the ship, two on a mast on the ships bow and one on the stern also providing meteorological data for the scientists on board as well as the ship's crew. Figure 4 shows NRV Alliance and attached meteorological instruments. Ship's radar is set to detect other ships, but thunderstorm clouds as well as coastline are also visible.

The *Meteo system* for automatized measurement of meteorological parameters on board NRV Alliance is configured from two Coastal Environmental Systems WEATHERPAK units, located on the forward mast at a height of approximately 23 meters above the sea surface and the third unit in the port side of the ship's stern, 15 meters above the sea surface. The instruments measure wind speed and direction, air temperature, relative humidity and barometric pressure and solar irradiance. The measured wind speed and direction are relative to the ship's movement. The movement of the ship is also provided from NRV Alliance and the true wind speed and direction is recomputed in the real time.

The *Coastal Monitoring Buoy* (Figure 5) measures wind speed (m/s) and direction (de-

Figure 4. NRV Alliance and attached meteorological instruments, display from automatic meteorological station, ship's radar display and Dallaporta research vessel.

Slika 4. Istraživački brod Alliance sa pripadajućim meteorološkim instrumentima, prikazom podataka brodske automatske meteorološke postaje, brodskog radara i istraživački brod Dallaporta.

grees), air temperature (degrees C), pressure (dBar), relative humidity (%), wave height (m) and period (s), sea current speed and direction and sea temperature. It is intended to be used in coastal waters, in ports and harbours and near off-shore platforms. A foam-filled polyform buoy carries the measuring system and the sensors, it is moored in a fixed position and operates on solar cells. It is possible to transfer measured data via radio signal to a nearby platform, but in the absence of any platform near the buoy the data were stored on an internal hard drive.

2.2.2 Oceanographic measurements

Most of the ship's time at sea was devoted to oceanographic measurements. Some of these activities can be performed in any weather, while other require light to moderate wind and waves to permit successful operations. Other oceanographic measurements are focused on specific phenomena that are best observed under specific weather conditions. Therefore, forecasting weather conditions as well as the sea state was important when making day to day schedule of activities. Particular properties and purpose of oceanographic instruments was important for the meteorologist to distinguish which parts of the daily forecast are significant for different types of measurements.

The *SEPTR* (Shallow-water Environmental Profiler in Trawl-safe Real-time configuration), developed by NATO Undersea Research Center - in collaboration with the US Naval Research Laboratory, Stennis Space Center is the instrument evolving from Barny adding an automated water column profiler, additional sensors and two-way communication via satellite at regular time intervals that allows transfer of measured data in the real time. Process of assembling the instrument on board, lowering it to the sea bottom, its search and retrieval is shown in Figure 6, with some examples how marine life can endanger the in-

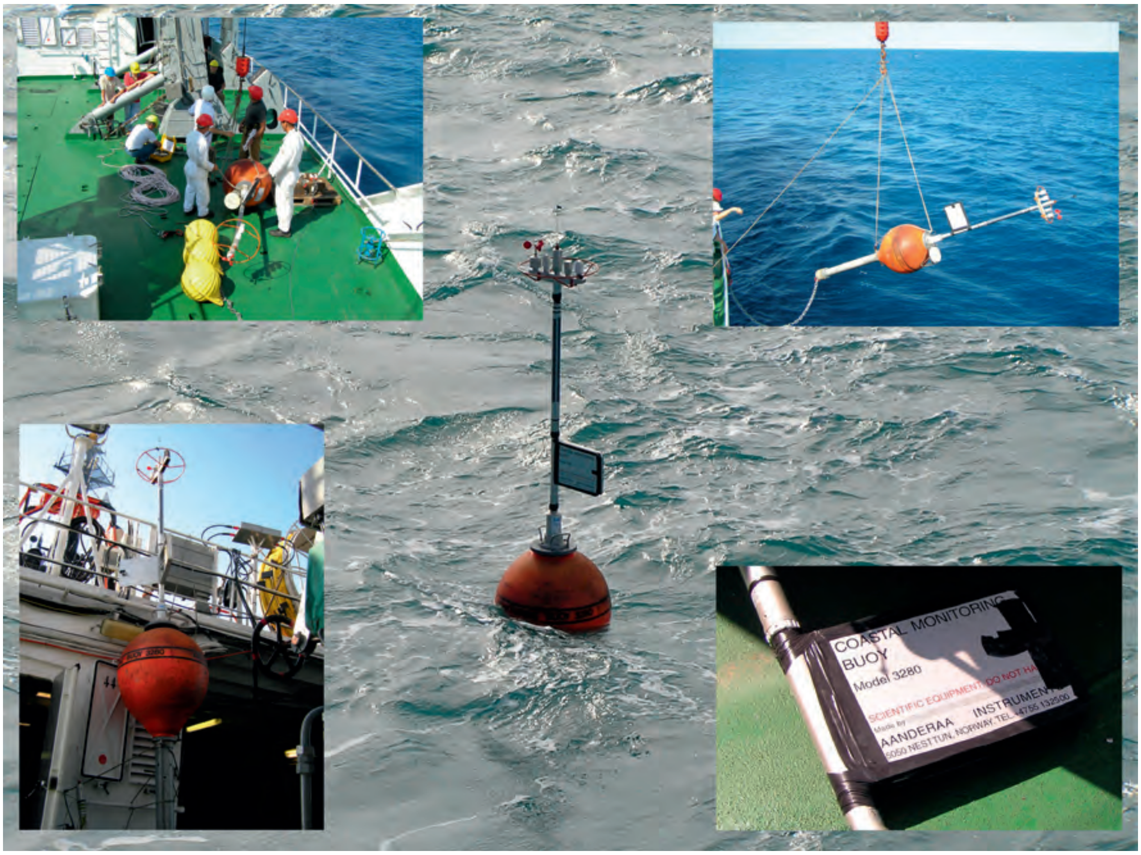

Figure 5. Coastal meteorological buoy, the way it is secured on the deck (bottom left) attached to the crane (top left), lowered into the sea (top right) and floats (background).

Slika 5. Obalna meteorološka plutača, osigurana na palubi (dolje lijevo), obješena na brodsku dizalicu (gore lijevo), spuštena u more (gore desno) i pluta (u pozadini).

struments operations in Figure 7, causing loss of time and data during the field experiment as well as damage to the instrument.

Barny moorings contain ADCPs and wave/tide gauges. The fiberglass instrument housing is surrounded by a concrete ring. The instrument was developed by SACLANT Center in collaboration with the Naval Research Laboratory (NRL), shown in Figure 6, H and I.

AQUAshuttle is an instrument which can be towed beneath the sea at controllable depths, it carries instruments for measuring depth, temperature, salinity, chlorophyll fluorescence, bioluminescence, nutrient, redox, and dissolved oxygen.

The *CTD on Alliance* (Figure 7) measures vertical profiles of the temperature, conductivity and pressure underwater. Additional sensors for oxygen, turbidity and irradiance are installed.

Lagrangian drifters (Figure 7) have been released from Alliance, their positions were received with 30 or 60 minutes interval (depending on type) by Tiros-N satellites and provided mesoscale surface circulation. Depending on the instrument, lagrangian drifters can also measure sea surface temperature, upwelling radiance and downwelling irradiance.

The *waverider* (Figure 7) is a spherical, 0.9m diameter, buoy which measures wave height and wave direction. The direction measurement is based on horizontal motions measurements. The buoy also measures surface temperature.

The *ADCP (Acoustic Doppler Current Profiler)* system on board the NRV Alliance collected measured data on temperature and conductivity every 1 s in 40 vertical bins with a vertical resolution of 4 m. To avoid the pollution by the noise of the ship, the transducers were in a wall of the ship's keel, at 5.20 m below the surface.

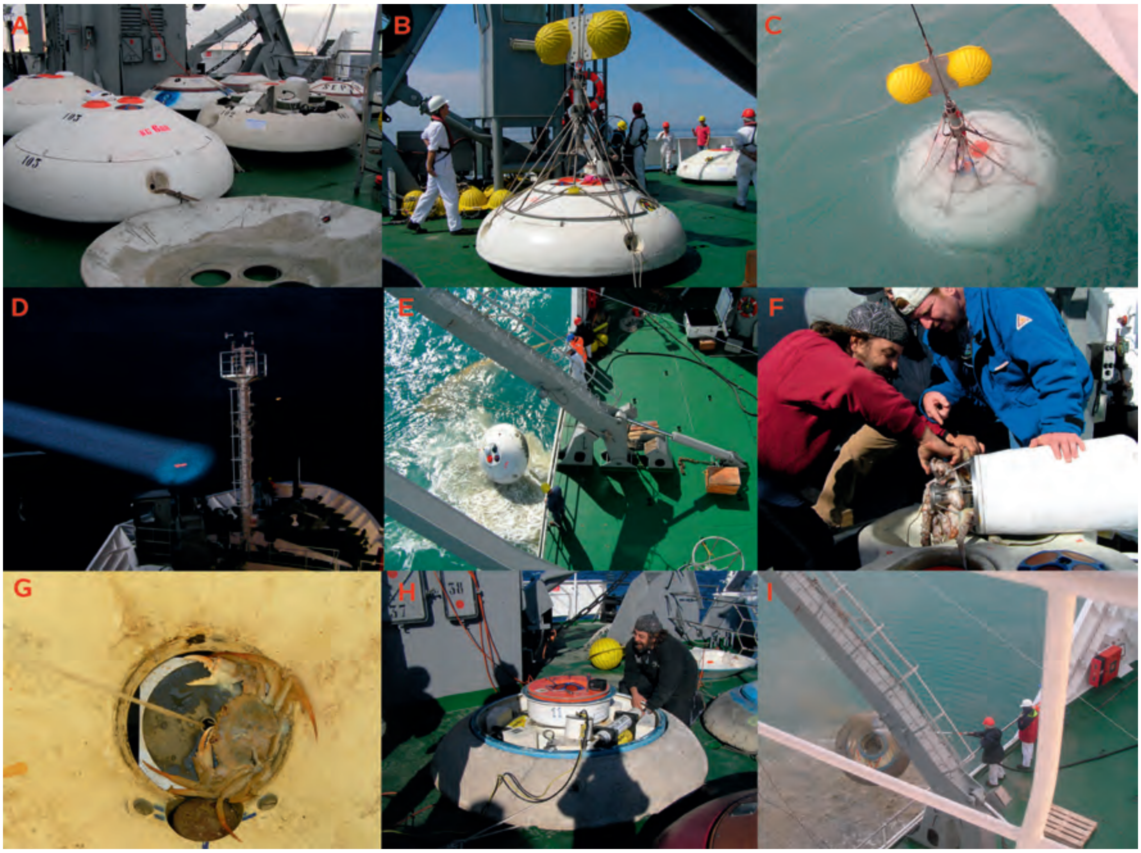

Figure 6. Process of assembling the SEPTR on board (A), attaching it to the crane (B), lowering it to the sea bottom (C), the search for it (D) and retrieval (E) with some examples how marine life can endanger the instruments operations (F) and (G) causing malfunction of the instrument. Assembling (H) and retrieval (I) of Barny are also shown.

Slika 6. Sastavljanje instrumenta SEPTR na palubi (A), podizanje brodskom dizalicom (B), spuštanje na dno mora (C), potraga za instrumentom (D) i izvlačenje iz mora (E) s primjerima kada morske životinje ugrožavaju rad instrumenta (F) i (G). Sastavljanje (H) i izvlačenje iz mora (I) instrumenta BARNY su također prikazani.

The *Sw 104 core sampler* is an instrument designed to take sediment samples from the sea bottom providing data on parameters such as density, speed of sound and magnetic susceptibility.

The *MSS (Microstructure) profiler* (Figure 8) is a probe for the measurement of microstructure and turbulence in the sea. The instrument is equipped with microstructure and hydrographic sensors and manufactured in cooperation with Sea&Sun Technology GmbH.

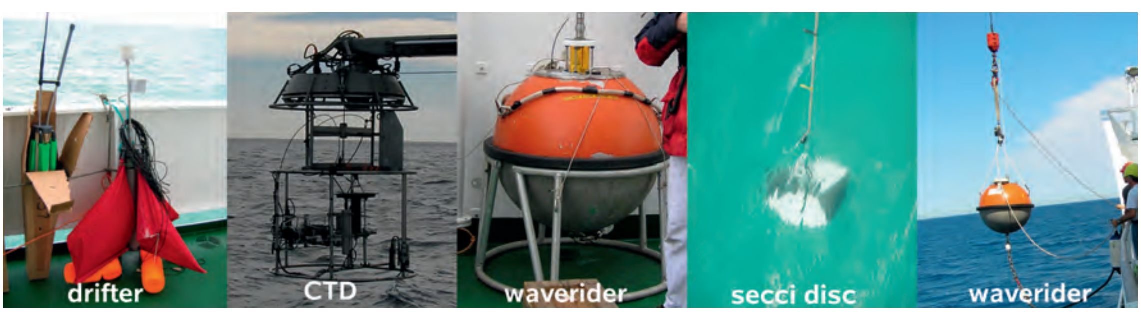

Figure 7. From left to right: lagrangian drifters, CTD, waverider on deck, Secci disc, waverider lowered to the sea.

Slika 7. S lijeva na desno: lagranžijanske plutače, CTD, valomjer na palubi, disk za mjerenje vidljivosti, valomjer spušten u more.

Figure 8. From left to right: ROV, waverider, lowering of the CTD chain and microstructure measuring system.

Slika 8. S lijeva na desno: podmornica na daljinsko upravljanje, valomjer, spuštanje CTD lanca u more i sustav za mjerenje turbulencije u moru.

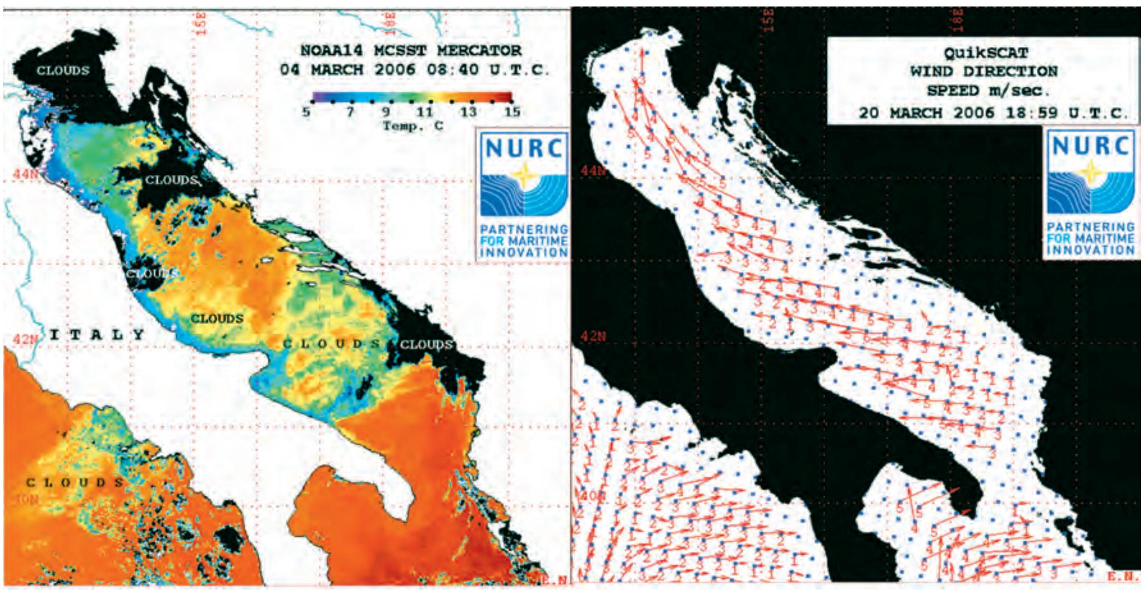

Figure 9. Pictures available on board from AVHRR (left) and QuickSCAT (right).

Slika 9. Satelitske slike dostupne na brodu sa AVHRR (lijevo) i QuickSCAT (desno) sustava.

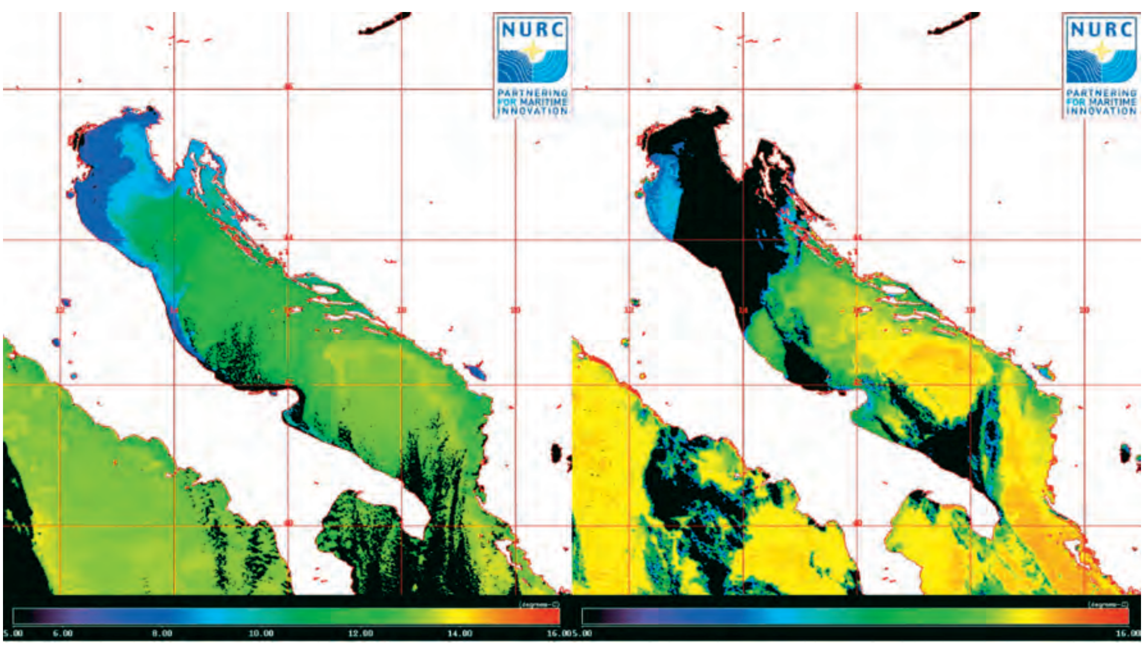

Figure 10. Pictures available on board from MODIS TERRA (left) and MODIS AQUA (right).

Slika 10. Slike dostupne na brodu sa MODIS TERRA (lijevo) i MODIS AQUA (desno) sustava.

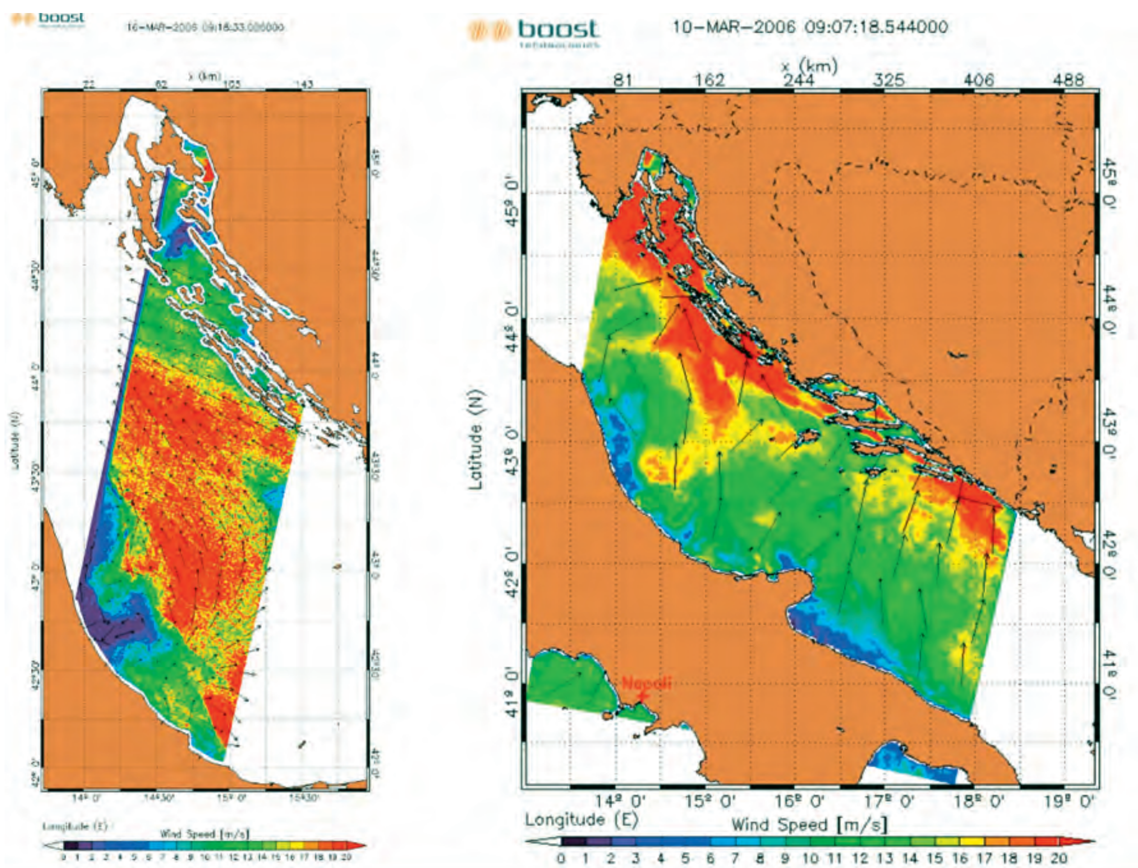

Figure 11. Pictures available on board from ENVISAT (left) and RADARSAT (right).

Slika 11. Slike dostupne na brodu sa ENVISAT (lijevo) i RADARSAT (desno) sustava.

High-resolution *PRR (Profiling Reflectance Radiometer)* was used to measure ocean colour, the instrument provided by Institute of Oceanography and Fisheries, Split, Croatia.

The *ROV (Remotely Operated Vehicle)* (Figure 8) is Sub-Atlantic's fully electric CHEROKEE was used for search and retrieval of the oceanographic instruments lost on the sea floor.

The ac-9 *spectrophotometer* determines the spectral transmittance and spectral absorption of water over nine wavelengths by determining absorption and attenuation coefficients.

2.2.3 Remote sensing data

The remote sensing data were used to observe the sea surface temperature and the ocean colour, radiometry and scatterometry and derive the wave and wind fields. Satellite figures of sea surface properties were used for detection of transient phenomena that were in the scope of the study of the DART cruises. This data allowed planning specific actions while at sea and in real-time and, consequently, fetching the small scale disturbances in the flow with in-situ measurements.

The *AVHRR (Advanced Very High Resolution Radiometer)* data provided satellite sea surface temperature images (Figure 9) in graphics interchange format (gif) as well as in ascii and NetCdf formats. Measurement platforms are NOAA12, NOAA16 and NOAA17 satellites of the series TIROS-N. They fly in circular sun-synchronous orbits at an altitude of approximately 840 km, with an inclination of 98 degrees from the equator and with the spatial resolution of 1.1 km at the nadir. The AVHRR sensor provides global (pole to pole) onboard collection of data from all spectral channels. For details see: http://www2.ncdc.noaa.gov/docs/klm/html/c3/sec3-1.htm

Using *NASA's Quick Scatterometer (Quik SCAT),* surface wind speed and direction images in graphics interchange format (gif) were provided (Figure 9), as well as ascii files with wind

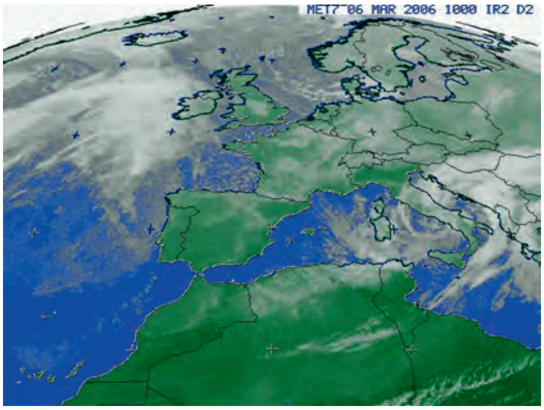

Figure 12. An example of the picture available on board from METEOSAT.

Slika 12. Primjer METEOSAT slike koja je bila dostupna na brodu.

speed and direction data. The satellite was also equipped with a specialized microwave radar (SeaWinds instruments), that measured near-surface wind speed and direction under all weather and cloud conditions over the Earth's seas. During each orbit, a 1,800 Km swath was performed, providing approximately 90% coverage of the Earth's oceans every day. The SeaWinds instruments provided wind-speed measurements of 3 to 20 meters/second, with an accuracy of 2 meters/second; and direction, with an accuracy of 20 degrees. For details see: http://winds.jpl.nasa.gov/missios/quickscat/index.cfm

The *MODIS (Moderate Resolution Imaging Spectroradiometer)* flight instruments are integrated on the Terra and Aqua spacecrafts and offer an unprecedented look at terrestrial, atmospheric, and ocean phenomenology for a wide and diverse community of users throughout the world (Figure 10). The MODIS instrument provides high radiometric sensitivity (12 bit) in 36 spectral bands ranging in wavelength from 0.4 μm to 14.4 μm. The responses are custom tailored to the individual needs of the user community and provide exceptionally low out-of-band response. For more information (http://modis.gsfc.nasa.gov/)

MERIS (MEdium Resolution Imaging Spectrometer Instrument) is operating in the solar reflective spectral range. Each of the fifteen spectral bands has a programmable width and location in the 390 nm to 1040 nm spectral range. The instrument scans the Earth's surface by the so called "push-broom" method with a spatial resolution of 300 m, reduced to 1200 m by the on board combination of four adjacent samples across-track over four successive lines. MERIS allows global coverage of the Earth in 3 days. For more information (http://envisat.esa.int/dataproducts/meris/CNTR3.htm).

Using ENVISAT – ASAR instrument, the ground is illuminated by a radar beam from the satellite, as the satellite moves, the complex echo signal from the ground is coherently added yielding the same result as if a long antenna (so called *Synthetic Aperture Radar - SAR*) is illuminating the ground (Figure 11). More details on (http://envisat.esa.int/dataproducts/asar/-CNTR3-1.htm).

The *RADARSAT*-1 satellite is equipped with a state-of-the-art Synthetic Aperture Radar (SAR) that can be steered to collect data over a 1,175 km wide area using 7 beam modes, providing images (Figure 11) with a range of resolutions, incidence angles, and coverage areas. For more information (http://www.rsi.ca/products/sensor/radarsat/radarsat1.asp).

Figures obtained from METEOSAT satellite, as shown in Figure 12, were also available and were the only ones showing the cloudiness distribution and structure. Data from other satellites was filtered in such a way to set all clouds to missing data.

3. THE FIELD EXPERIMENTS

Two field experiments were organised to cover different weather regimes and corresponding responses of the Adriatic Sea. The first one started on 27th February and finished on 28th March 2006. That period covers several episodes of severe weather with strong wind, particularly bura and sirocco. The second field experiment started on 13th and finished on 31st August 2006. It was characterized by calm weather and low wind regime that was disturbed only by few local convective thunderstorms.

During bura periods, strong and persistent N and NE winds over the eastern Adriatic change direction towards the NW over the western areas of the open middle and south Adriatic. The wind has a positive curl over the open Adriatic (Jurčec and Brzović, 1995; Enger and Grisogono, 1998). It is expected that the usual ocean circulation of the Adriatic Sea is modified in strong wind episodes (eg. Orlić et al., 1994).

Due to high spatial variability of the wind speed and direction in bura episodes, the modelling of the Adriatic Sea circulation requires a high-resolution atmospheric model to describe the atmosphere-ocean interaction properly.

3.1 27th February to 28th March 2006

NRV Alliance sailed from La Spezia on 27th February 2006 in the evening. The first 36 hours are devoted to crossing the Ligurian and Tyrhenninan Sea and reach the Strait of Messina. After the acoustic tests performed in the Strait of Messina in the morning of 1st March, transfer continued through the Ionian Sea and reached Adriatic by the morning on 2nd March when first tests of the instruments were performed. The following two days, the moorings in the Manfredonia bay (several SEPTRs and Barnys) were laid as well as the wave rider and a meteorological buoy. These operations require relatively calm sea, so had to be finished before the wind speed increased the following day. The weather conditions on 5th March with strengthening wind, but sea state ony starting to deteriorate, allowed recovery of 5 Barnys closest to Italy on the Gargano-Split transect.

During the first two days of March a cold front passed, the wind shifted from strong southwest to strong northwest. In the next few days, wind shifted to southwest, the air temperature in the area was rising. Most of Europe was under a large cyclone. The secondary cyclone formed on 4th March. As it was passing, the wind direction shifted again. The cold air was advected from the northwest. The precipitation shifted from rain to snow and the bura wind reached gale force on 6th March. The next day was dry, but bura remained gale and continued so until 8th March. Due to this bura episode, the port call to Split was prolonged until the early morning on 8th March.

Bura weakened on 8th and shifted to light to moderate sirrocco on 9th March. Wind conditions allowed to continue recovering and deploying Barnys along the Gargano-Split line as well as in the area between Mljet and Lastovo on 8th and 9th March. Sirocco strengthened, pressure dropped, weather remained mostly cloudy which did not disturb CTD probing that continued until 11th March when several Barnys were deployed along Gargano-Split line under moderate wind conditions. Bura strengthened on eastern Adriatic as cyclone strengthened in the Ionian sea. On 11th and 12th March, aquashuttle was towed, but it was given up in the evening on 12th due to gale wind and wave activity that prevented further useful activities. In bura conditions, wind on the open sea close to Italian coast is northwest so the waves have a long fetch to grow before reaching Gargano area. Alliance steamed towards Dubrovnik and continued CTD probing Adriatic on the line from Dubrovnik to Bari on 13th March. Aquashuttle measurements continued on 14th March until 17th when port call to Bari was made. During this tow, meteorological bouy was retrieved on 15th March since inspection by workboat has shown that it was damaged.

Cloudy weather with light wind on 19th and 20th March allowed optics and turbulence measurements as well as taking some core samples. The wind and wave conditions continued to be favourable for recovery of Barnys and SEPTRs from Manfredonia bay started in the evening on 19th until 21st March. Shallow cyclone approached Adriatic, weather became more cloudy and sirocco wind strengthened. This activity continued with deployment of repaired Barneys on Gargano-Split line on 22nd in the morning as well as in the area between Lastovo and Mljet in the afternoon. Strong to gale sirocco wind in the area made mooring of the last two Croatian Barneys quite difficult. During the nights, turbulence measurements continued with the search for the lost SEPTR device. Unfortunately it remained to be lost, at least for the research community involved in the DART project. On 24th March NRV Alliance sailed towards La Spezia. The weather was partially cloudy, mostly from interaction of moist air from the sea with the thermals rising from the Apennines. Wind was light, direction varied from southeast to southwest and the air temperature was slowly rising.

3.2 13th to 31st August 2006

During the first half of August 2006 the weather was unstable with showers and local thunderstorms. The area was under broad cyclone with moist and unstable air. From 15th to 19th August, the weather was more stable, sunny and warm since high pressure field spread from the southern Mediterranean. But more unstable weather with showers followed in the period from 20th to 24th August due to more

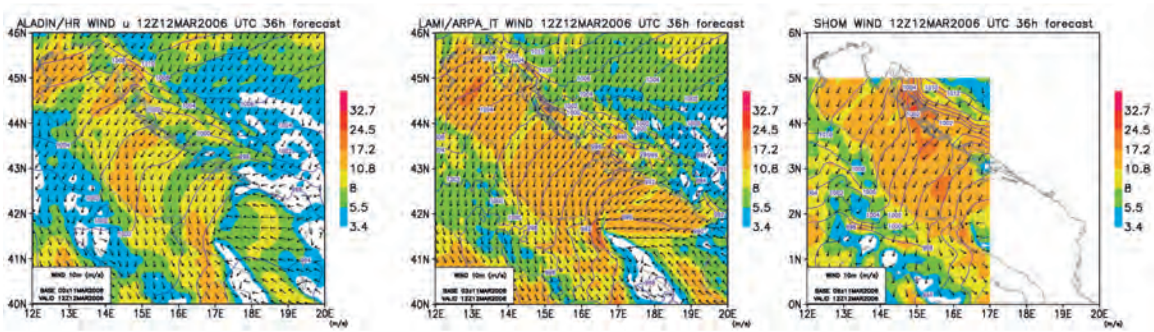

Figure 13. Forecast 10 m wind for 12 UTC on 12^th March 2006 using Aladin-Croatia (left), LAMI (centre) and Aladin-France (right).

Slika 13. Prognoza vjetra na 10 m za 12 UTC 12-tog Ožujka 2006. dobivena operativnim modelima ALADIN Hrvatska (lijevo), LAMI (sredina) i ALADIN Francuska (desno).

moist and unstable air. The final week of August, from 25th to 31st, was cold for that time of the year, with rain, showers and thunderstorms since the area was again under a cyclone where atmospheric fronts brought cold air from north and northwest. Although the wind and wave conditions were not so pleasant during the transfer from La Spezia to Otranto and back, the weather conditions during the whole period allowed planned actions and did not disturb the measurements.

4. MODEL TO MODEL AND MODEL TO MEASURED DATA COMPARISON

Each meteorological service involved in the DART project was running their forecast model at the mainframe computer at home then transfer the relevant forecast fields to the geos2 server at NURC (NATO Undersea Research Centre). The forecast fields transferred to the server were longitudinal and meridional component of 10m wind, 2m temperature and relative humidity, total cloud cover, mean sea level pressure, precipitation, shortwave and longwave radiation flux as well as latent and sensible heat fluxes. The data from Aladin and LAMI models were transferred in GRIB format, while COAMPS fields were transferred in some format specific for that model. The data were then transferred to the geos2 mirror server on board Alliance. Only after that final transfer did the meteorologist on board the ship had access to the new forecast run and

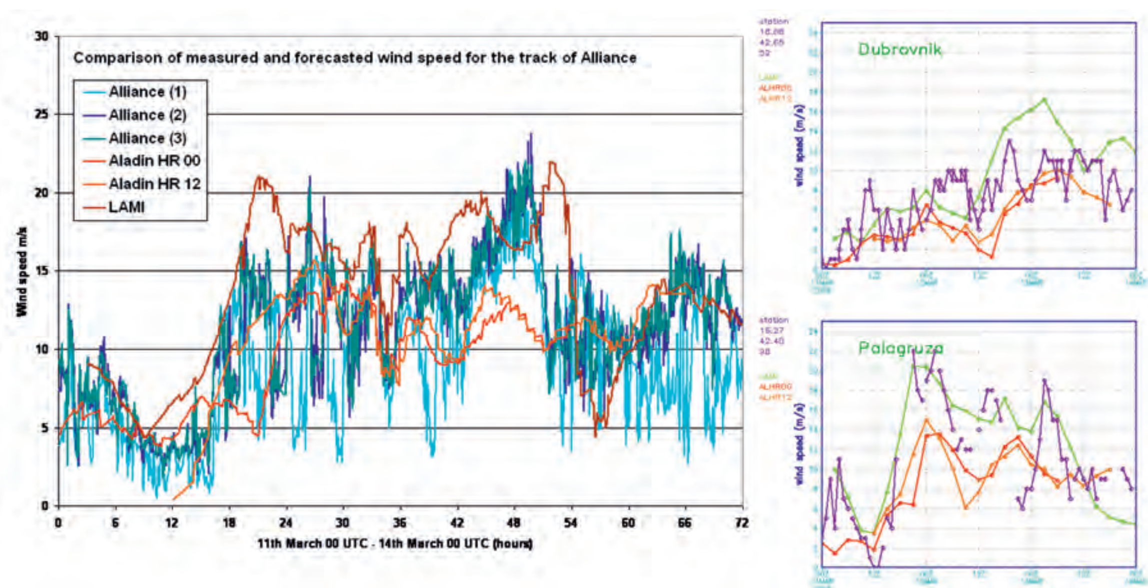

Figure 14. The forecast wind speed compared to the one measured on Alliance and on SYNOP stations.

Slika 14. Usporedba prognozirane brzine vjetra sa mjerenjima na brodu Alliance i sinoptičkim postajama.

could plot the fields. The data transfer took much time even when the link was good, which seldom happened. Therefore, the amount of data to be transferred had to be reduced as much as possible and was restricted to the raw model output. The time interval of the forecast fields was prolonged from 1 to 3 hours. Much of the forecast postprocessing was done on board. A small postprocessing operational suite that produced figures of the forecast fields and comparison to measured data was established. Since the transfer of data to the ship often happened late in the day, long forecast runs were very desirable when planning actions for the next days. ALADIN runs were prolonged from 54 to 72 hours between winter and summer field experiments while LAMI runs were 72 hours the whole time.

4.1 Severe bura case

The case of bura on 13th March 2006 was a severe one. Bura spread over the whole Adriatic, the wind was northeastern on the eastern Adriatic shore, but changed direction to northwest on the western Adriatic. The weather situation developed as follows:

On 9th March atmospheric pressure was decreasing, southeastern wind strengthened. The next day, a cyclone was deepening and moving southeastward. It reaches Ionian sea on 11th March. Bura first started on northern and central Adriatic. It spread over the whole Adriatic on 12th and 13th March and strengthened as the pressure gradient over the Dinaric Alps was increasing, the pressure inland increased and the cyclone above Ionian sea deepened. As the cyclone moved away and filled in, bura weakened in the following days.

In the weather situation with strong and severe wind, the wind speed in the Aladin forecast decreases too much above the sea giving too low wind speed and sometimes qualitatively significantly different field (Figure 13). Both Aladin Croatia and LAMI show banners of stronger and weaker wind over the open sea whose structure reflects the terrain configuration upstream. Low resolution of Aladin France does not show the same structure in the flow, although the pressure field is similar. Above the open sea, LAMI predicts stronger wind than Aladin and the wind speed maximum is found off-shore while Aladin gives maximum wind speed on the east-

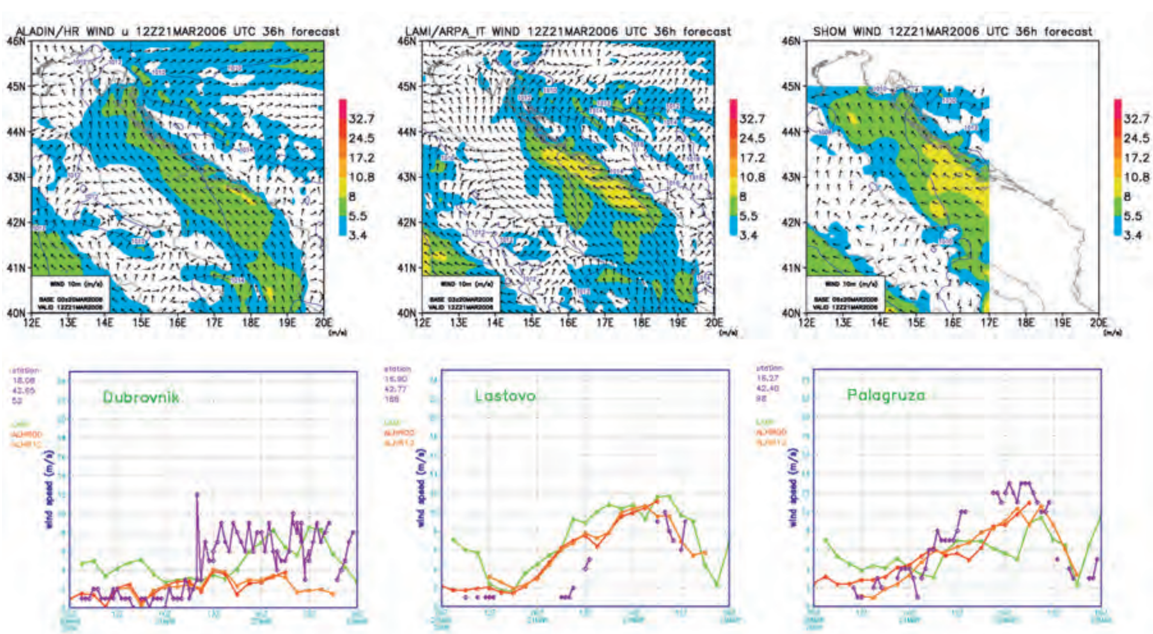

Figure 15. Forecast 10 m wind (top row) for 12 UTC on 21^st March 2006 using Aladin-Croatia (left), LAMI (Center) and Aladin-France (right) and the forecast wind speed compared to the one measured on SYNOP stations (bottom row).

Slika 15. Prognoza brzine vjetra na 10 m (gornji red) za 12 UTC 21-og Ožujka 2006. dobivena modelima ALADIN Hrvatska (lijevo), LAMI (sredina) i ALADIN Francuska (desno), te usporedba prognozirane brzine vjetra sa mjerenjima na sinoptičkim postajama (donji red).

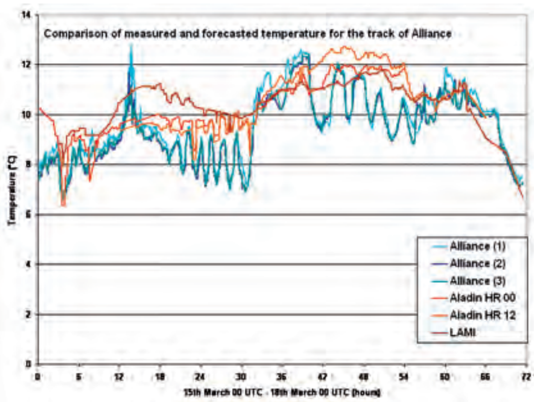

Figure 16. The forecast air temperature compared to the one measured on Alliance for the period from 00 UTC on 15th to 00 UTC on 18th March 2006.

Slika 16. Usporedba temperature zraka sa mjerenjima na brodu Alliance za razdoblje od 00 UTC 15-tog do 00 UTC 18-tog Ožujka 2006.

ern Adriatic shore just below the mountains (Figure 14).

The wind speed measured on Alliance is compared to the forecasts on Figure 14. When the vessel is close to Italian coast, LAMI forecast compares better to the measured data, but close to Croatian coast, Aladin performs better. In the open sea the results are not always conclusive.

4.2 Severe jugo case

It would be interesting to study a situation with another familiar severe wind that is characteristic for the Adriatic. This is southeastern wind called sirocco or jugo. The wind speed of the jugo wind is often underestimated for the Dubrovnik area with Aladin model. It would be informative to know how well is it modelled in the open sea.

On 19th and 20th March southeastern wind strengthened higher in the atmosphere, temperature was rising as warm and moist air was advected to the area. It was more cloudy. Shallow cyclone formed above western Mediterranean and was slowly moving eastward. From 21st to 23rd March it was rainy and wet as the warm and moist air continued to accumulate in the area.

Aladin and LAMI predict different wind speed distribution, LAMI gives stronger wind for the eastern part of the southern Adriatic (Figure 15). When the forecast data are compared to the measurements from the Alliance (figure not shown), the measured wind speed is much stronger than predicted with any model for the open sea between Lastovo and Mljet.

The measured variability in wind speed and direction is much larger than anticipated by the modelled wind gusts, even for the stern anemometer which is situated much closer to the sea level than the ones on the bow.

4.3 Local temperature variations

In March, the western Adriatic sea current was much colder than the open sea of the central and southern Adriatic. As a consequence, the sea surface temperature was changing abruptly as the ship would sail in and out of the current (Figure 16). The temperature of the air above it would change too, as the air closer to the Italian coast was much colder than the air above the open sea. In low wind situation, the warm air would slowly move towards the cold sea current and cooled producing lower visibility and fog closer to the coastline. The temperature gradient, fog and low cloudiness were not predicted by any meteorological model since the cold western Adriatic current was not recognized in the sea surface temperature field. Using input from some ocean model or assimilating sea surface temperature in high resolution should improve this.

The temperature forecast field predicted by Aladin and LAMI is sometimes surprisingly different as a consequence of different heat and radiation fluxes (Figure 17). Different schemes used to parameterize physical effects give slightly different fluxes but their balance might produce different result. Figure 17 shows predicted temperature field, as well as heat fluxes. Although the differences above land are much larger, noticeable discrepancy in the forecast may also be noticed above the sea surface.

The sea surface temperature distribution is under influence of the sea currents which are often modified by the wind conditions. Therefore, the accurate prediction of some local weather phenomena would require carefully balanced coupled ocean-atmosphere model run.

5. CONCLUSIONS AND OUTLOOK

During DART field experiment, a set of measured and modelled data of ocean and atmosphere was collected. This article describes

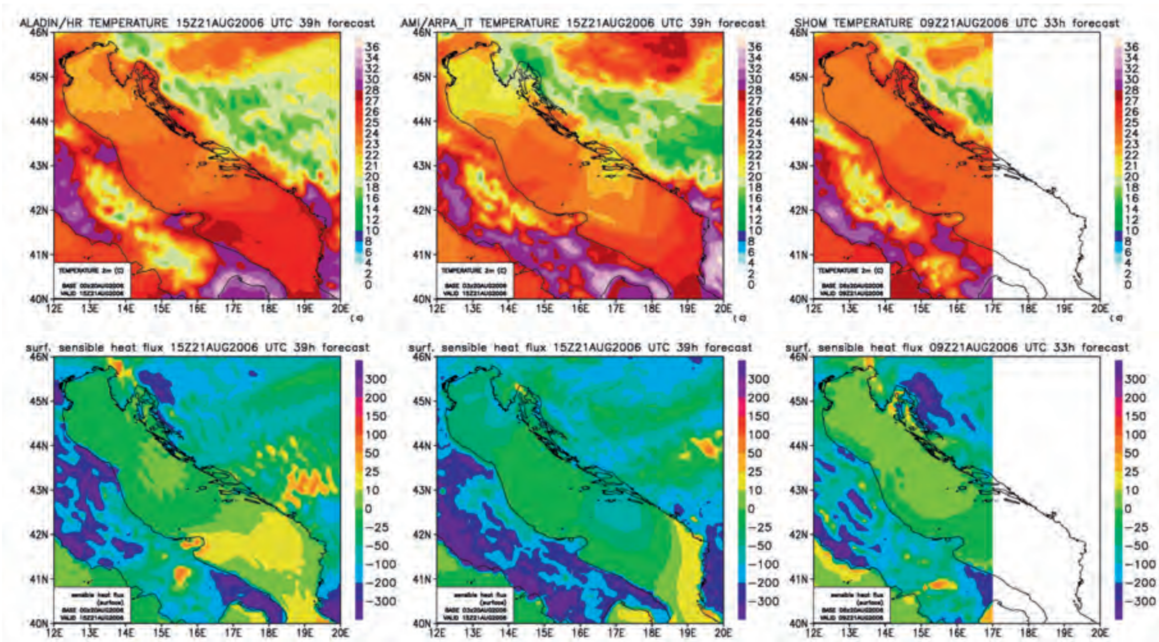

Figure 17. Forecast 2m temperature (top row) and surface sensible heat flux (bottom row) for 9 UTC on 21^st August 2006 using Aladin-Croatia (left), LAMI (centre) and Aladin-France (right).

Slika 17. Prognoza temperature na 2m (gornji red) i toka senzibilne topline pri tlu (donji red) za 9 UTC 21. Kolovoza 2006. dobivena modelima ALADIN Hrvatska (lijevo), LAMI (sredina) i ALADIN Francuska (desno).

the meteorological aspects of the two field experiments when the special measurements were done at sea, from 27^{th} February to 29^{th} March 2006 and from 13^{th} to 31^{st} August 2006. It includes the description of meteorological conditions that affected the special measurement activities, the instruments and remote sensing data used in the experiment as well as the technical details involved in model and measurement data collection and transfer.

The main purpose of DART was to test the real time measurement and modelling capabilities for the Adriatic Sea that were available at the time of the field experiments. These capabilities are described here.

Two severe weather events are described as well as local temeprature veriations that are caused by the cold sea current along the Italian coastline. The preliminary analysis of the meteorological model results revealed several discrepancies that are only briefly analized here.

The preliminary analysis of the measured and modelled data reveals several issues that can be adressed in further studies. These require more detailed insight into the involved processes, meteorological model evaluation as well as the complex air-sea interaction mechanisms.

The predicted large scale pressure field as well as the upper air flow is often similar between different meteorological models used for the weather forecast. But these lead to significant differences in the predicted 10m wind. Forecasts of other meteorological fields close to surface as well, as fluxes of meteorological parameters through it, also differ. It is difficult to conclude if these discrepancies are the consequence of different parametrisations of surface processes or simply different formulas used to interpolate meteorological quantities from model levels to relevant meteorological heights (10 and 2 meters).

Numerical weather prediction models gives heat and radiation fluxes as output, Aladin too. These fluxes can be used to force oceanographic models. Such usage in the framework of the MFSTEP (Mediterranean Forecasting System Towards Environmental Prediction) project revealed several shortcomings in the model configuration. Several proposed modifications (Brožkova et al, 2006) and a specific model configuration tailored for the specific needs of the MFSTEP project has improved the output fluxes as well as general weather forecast. The modifications in the horizontal diffusion and physical parametrization schemes described in Brožkova et al (2006) were included in the operational version of the Aladin model run in Croatia prior to the start of the DART project.

Ocean circulation influences the sea surface temperature distribution which affects atmospheric stability and the air flow above. For example, in their analysis of idealized non-linear flow over idealized mountain, Kraljević and Grisogono (2006) found that low level jet and the bura front propagation are affected by the sea surface temperature. Since bura flow also affects ocean circulation, coupling atmospheric model to an ocean circulation one should improve wind forecast on the open sea, as well as other meteorological parameters.

Improved knowledge of vertical gradients of meteorological quantities in the layer above the sea surface, particularly air temperature, wind speed and direction in different weather, wave and ocean conditions should lead to better understanding and description of the air-sea interaction processes. Inclusion of the latter in the operational meteorological models used for numerical weather prediction would significantly improve the weather forecast not only above the sea surface, but also for the coastal areas and inland.

ACKNOWLEDGEMENTS

The author wishes to thanks Michael Rixen from the NATO research center in La Specia and Jeff Book from the NRL ocean research center in Mississippi for invitation to get involved in the project, as well as the scientists, technicians and the ship crew on board Alliance and on ground for their time and support.

The reviewers are also acknowledged, as their suggestions improved the manuscript.

REFERENCES

Brožkova, R., M. Derkova, M. Belluš and A. Farda, 2006: Atmospheric forcing by ALADIN/MFSTEP and MFSTEP oriented tunings. Ocean Sciences 2, 113–121.

Enger, L. and B. Grisogono, 1998: The response of bora-type flow to sea surface temperature. Quarterly Journal of the Royal Meteorological Society 124, 1227–1244.

Ivatek Šahdan, S. and M. Tudor, 2004: Use of high-resolution dynamical adaptation in operational suite and research impact studies. Meteorologische Zeitschrift 13(2), 1–10.

Jurčec, V. and N. Brzović, 1995: The Adriatic bora: special case studies. Geofizika 12, 15–32.

Kraljević, L., B. Grisogono, 2006: Sea-surface temperature effects on 3D bora-like flow. Meteorologische Zeitschrift 15(2), 169–177.

Orlić, M., M. Kuzmić and Z. Pasarić, 1994. Response of the Adriatic Sea to the bora and sirocco forcing. Continental Shelf Research 14, 91–116.

Rixen, M., J. Book, A. Carta, V. Grandi, L. Gualdesi, R. Stoner, P. Ranelli, A. Cavanna, P. Zanasca, G. Baldasserini, A. Trangeled, C. Lewis, C. Trees, R. Grasso, S. Giannechini, A. Fabiani, D. Merani, A. Berni, M. Leonard, P. Marin, C. Rowley, M. Hulbert, A. Quaid, W. Goode, R. Preller, N. Pinardi, P. Oddo, A. Guarnieri, J. Chiggiato, S. Carniel, A. Russo, M. Tudor and L. Vandenbulcke, 2008: Improved ocean prediction skill and reduced uncertainty in the coastal region from multi-model super-ensembles. Submitted to Nature.

Vilibić, I., J. W. Book, G. Beg Paklar, M. Orlić, V. Dadić, M. Tudor, P. J. Martin, M. Pasarić, B. Grbec, F. Matić, H. Mihanović and M. Morović, 2008. West Adriatic coastal water summertime excursion into the East Adriatic. Submitted to JMS special issue.